THE PAST CENTURY.

Its Progress in Great Subjects.

A SET OF REMARKABLE ARTICLES

Thirteenth Paper of the Series, by Thomas C. Clarke,

(Past President American Society Civil Engineers, Member and Telford Gold Medallist Institute Civil Engineers, London.)

"CIVIL ENGINEERING."

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The material prosperity of the last century is due to the cooperation of three classes of men: the man of science, who lives only for truth and the discovery of nature's laws; the inventor, eager to apply these discoveries to money-making machines and processes; and the engineer, trained in mathematical investigation and in knowledge of the physical conditions which govern his profession, which is the mechanical application of the laws of nature.

Engineering is sometimes divided into civil, military and naval engineering. The term civil engineering, which will be here described, is often used by writers as covering structural engineering only, but it has a much wider meaning.

The logical classification is: statical engineering, including that of all fixed bodies, and dynamical, covering the movement of all bodies by the development and application of power.

Statical engineering can be again subdivided into structural engineering, or that of railways, highways, bridges, foundations, tunnels, buildings, &c., also, into hydraulic engineering, which governs the application of water to canals, river improvements, harbors, the supply of water to towns and for irrigation, disposal of sewage, &c.

Dynamical engineering can be divided into mechanical engineering, which covers the construction of all prime motors, the transmission of power, and the use of machines and machine tools. Closely allied is electrical engineering, the art of the transformation and transmission of energy for traction, lighting, telegraphy, telephoning, operating machinery and many other uses, such as its electrolytic application to ores and metals.

Then we have the combined application of statical, mechanical and electrical engineering to what is now called industrial engineering, or the production of articles useful to man. This may be divided into agricultural, mining, metallurgical and chemical engineering.

Surely this is a vast field, and can only be hastily described in the sketch which we are about to give.

STRUCTURAL ENGINEERING.

Structural engineering is the oldest of all. We have not been able to surpass the works of the past in grandeur or durability. The pyramids of Egypt still stand, and will stand for thousands of years. Roman bridges, aqueducts and sewers still perform their duties. Joseph's canal still irrigates Lower Egypt. The great wall of China, running for fifteen hundred miles over mountains and plains, contains one hundred and fifty millions of cubic yards of materials and is the greatest of artificial works. No modern building compares in grandeur with St. Peter's, and the mediæval cathedrals shame our puny imitations.

These mighty works were built to show the piety of the Church or to gratify the pride of Kings. Time and money were of no account. All this has now been changed. Capital controls, and the question of time, money and usefulness rules everything. Hence come scientific design and labor-saving machinery.

The engineer of our modern works first calculates the stresses on all their parts, and proportions them accordingly, so that there is no waste of material. Hand labor has given place to steam machinery. All parts are interchangeable, so that they can be made and fitted together in the least possible time, as is seen every day in the construction of a steel-framed office building. Our workmen receive much higher wages than in the past, while time and cost have been diminished.

RAILWAYS.

The greatest engineering work of the nineteenth century was the development of the railway system which has changed the face of the world. Beginning in 1830 with the locomotive of George Stephenson, it has extended with such strides that, after seventy years, there are 466,000 miles of railways in the world, of which 190,000 miles are in the United States. Their cost is estimated at forty thousand millions of dollars, of which ten thousand millions belong to the United States.

The rapidity with which railways are built in the United States and Canada contrasts strongly with what has been done in other countries. Much has been written of the energy of Russia in building 3,000 miles of Siberian railway in five or six years. In the United States an average of 6,147 miles was completed every year during ten successive years, and in 1887 there were built 12,982 miles. The physical difficulties overcome in Siberia are no greater than have been overcome here.

This rapid construction is due to several causes, the most potent of which has been the need of extending railways over great distances with little money. Hence they were built economically, and at first in not as solid a manner as those of Europe. Steeper gradients, sharper curves, and lighter rails were used. This rendered necessary a different kind of rolling stock suitable to such construction. The swivelling truck and equalizing beam enabled our engines to run safely on tracks where the rigid European engines would soon have been in the ditch.

Our cars were made longer, and by the use of longitudinal framing much stronger. A great economy came from the use of annealed cast-iron wheels, with hardened tires, all in one piece, instead of being built up of spokes, hubs, and tires in separate parts. These wheels now seldom break, and cost much less than European wheels. As there are some eleven million car wheels in use in the United States the resulting economy is great.

It was soon seen that longer cars would carry a greater proportion of paying load, and the more cars that one engine could draw in a train, the less would be the cost. It was not until the invention by Bessemer in 1864 of a steel of quality and cost that made it available for rails that much heavier cars and locomotives could be used. Then came a rapid increase. As soon as Bessemer rails were made in this country, the cost fell from $175 per ton to $50, and now to $26.

Before that time a wooden car weighed sixteen tons, and could carry a paying load of twenty-five tons. The thirty-ton engines of those days could not draw on a level over thirty cars weighing 1230 tons.

The pressed steel car of to-day weighs no more than the wooden car, but carries a paying load of fifty tons. The heaviest engines have drawn on a level fifty steel cars, weighing 3,750 tons. In the one case, the paying load of an engine was 750 tons; now, it is 2,500 tons.

Steep grades soon developed a better brake system, and these heavier trains have led to the invention of the automatic brake worked from the engine, and also automatic couplers, saving time and many lives. The capacity of our railways has been greatly increased by the use of electric block signals.

The perfecting of both the railway and its rolling stock has led to remarkable results.

We have no accurate statistics of the early operation of American railways. In 1867 Poor's Manual estimated their total freight tonnage at 75,000,000 and the total freight receipts at $400,000,000. This was an average rate per ton of $5.33.

In 1899 Poor gives the total freight tonnage at 975,789,941 tons, and the freight receipts at $922,436,314, or an average rate per ton of 95 cents. Had the rates of 1867 prevailed, the additional yearly cost to the public would have been $4,275,000,000, or sufficient to replace the whole railway system in two and a half years.

This is an illustration only, but a very striking one. Everybody knows that such high rates of freight as those of 1867 would have checked traffic. This much can surely be said: the reduction in cost of operating our railways, and the consequent fall in freight rates, have been potent factors in enabling the United States to send abroad last year $1,156,000,000 worth of exports, and to flood the world with our food and manufactured products.

BRIDGE BUILDING.

In early days the building of a bridge was a matter of great ceremony, and it was consecrated to protect it from evil spirits. Its construction was controlled by priests, as the title of the Pope of Rome, "Pontifex Maximus" indicates.

Railways changed all this. Instead of the picturesque stone bridge, whose long line of low arches harmonized with the landscape, there came the straight girder or high truss, ugly indeed, but quickly built, and costing much less.

Bridge construction has made greater progress in the United States than abroad. The heavy trains that we have described called for stronger bridges. The large American rolling stock is not used in England, and but little on the Continent of Europe, as the width of tunnels and other obstacles will not allow of it. It is said that there is an average of one bridge for every three miles of railway in the United States, making 63,000 bridges, most of which have been replaced by new and stronger ones during the last twenty years.

This demand has brought into existence many bridge-building companies, some of whom make the whole bridge, from the ore to the finished product.

Before the advent of railways, highway bridges in America were made of wood, and called trusses. Few of them existed before railways. The large rivers and estuaries were crossed in horse boats, a trip more dangerous than an Atlantic voyage now is. A few smaller rivers had wooden truss bridges. Although originally invented by Leonardo da Vinci, in the sixteenth century, they were re-invented by American carpenters. Some of Burr's bridges are still standing after more than one hundred years' use. This shows what wood can do when not overstrained and protected from weather and fire.

The coming of railways required a stronger type of bridge to carry concentrated loads and the Howe truss, with vertical iron rods, was invented, capable of 150-foot spans.

About 1868 iron bridges began to take the place of wooden bridges. Die-forged eyebars and pin connections allowed of longer panels and longer spans. The first long-span bridge was a single-track railway bridge of 400-foot span over the Ohio at Cincinnati, which was considered to be a great achievement in 1870.

The Kinzua viaduct, 310 feet high and over half a mile long, belongs to this era. It is the type of the numerous high viaducts now so common.

About 1885 new material was given to engineers, having greater strength and tenacity than iron, and commercially available from its low cost. This is basic steel. After many experiments, the proper proportions of carbon, phosphorus, sulphur and manganese were ascertained, and uniformity resulted. The open-hearth process is now generally used. This new chemical metal, for such it is, is 50 per cent. stronger than iron, and can be tied in a knot when cold.

The effect of improved devices and the use of steel is shown by the weights of the 400-foot Ohio River iron bridge, built in 1870, and a bridge at the same place, built in 1886.

The bridge of 1870 was of iron, had panels twelve feet long, and its height was forty-five feet, and span 400 feet.

The bridge of 1886 was of steel, had panels thirty feet long, and its height was eighty feet. Its span was 550 feet. The weights of the two were nearly alike.

The cantilever design, which is a revival of a very ancient type, came into use. The great Forth Bridge, in Scotland, 1,600 foot span, is of this style, as are the 500-foot spans at Poughkeepsie, and now a new one is being designed to cross the St. Lawrence near Quebec, of 1,800-foot span.

This is probably near the economic limit of cantilever construction, but the suspension bridge can be extended much farther, as it carries no dead weight of compression members.

The Niagara Suspension Bridge, of 810-foot span, built by Roebling, in 1852, and the Brooklyn Bridge, of 1,600 feet, built by Roebling and his son, twenty years after, marked a wonderful advance in bridge design.

Thirty years later, when a new bridge of 1,600 feet was wanted to cross another part of the East River at New York, the same lines of construction were followed, and they will be followed in the 2,700-foot span, designed to cross the North River, some time in the twentieth century. The only radical advance is the use of a better steel than could be had in earlier days.

Steel-arched bridges are now scientifically designed. Such are the new Niagara Bridge, of 840-foot span, and the Alexander II. Bridge, at Paris.

It is curious to see how little is said about these beautiful bridges, which the public takes as a matter of course. If they had been built fifty years ago, their engineers would have received the same praise as Robert Stephenson or Roebling, and justly so, as they would have been men of exceptional genius. When these bridges were built, in 1898, the path had been made so clear by mathematical investigation and the command of a better steel, that the task seemed easy.

That which marks more clearly than anything else the great advance in American bridge building, during the last forty years, is the reconstruction of the famous Victoria Bridge, over the St. Lawrence, above Montreal. This bridge was designed by Robert Stephenson, and the stone piers are a monument to his engineering skill. For forty winters they have resisted the great fields of ice borne by a rapid current. Their dimensions were so liberal that the new bridge was put upon them, although four times as wide as the old one.

The superstructure was originally made of plate-iron tubes, reënforced by tees and angles, similar to Stephenson's Menai Straits Bridge. There are twenty-two spans of 240 feet each, and a central one of 330 feet. Perhaps these tubes were the best that could be had at the time, but they had outlived their usefulness. Their interiors had become greatly corroded by the confined gases from the engines and the drippings from the chemicals used in cold storage cars. Their height was insufficient for modern large cars, and the confined smoke made them so dark that the number of trains was greatly limited.

It was decided to build a new bridge of open-work construction and of open-hearth steel. This was done, and the comparison is as follows: Old bridge, sixteen feet wide, single track, live load of one ton per foot; new bridge sixty-seven feet wide, two railway tracks and two carriage ways, live load five tons per foot.

The old iron tubes weighed 10,000 tons, cost $2,715,000, and took two seasons to erect. The new truss bridge weighs 22,000 tons, has cost between $1,300,000 and $1,400,000, and the time of construction was one year.

During his experience the writer has seen the rolling load of bridges increase from 2,000 to 4,000 pounds per lineal foot of track, with an extra allowance for concentrated loads.

The modern high office building is an interesting example of the evolution of a high-viaduct pier. Such a pier of the required dimensions, strengthened by more columns strong enough to carry many floors, is the skeleton frame. Enclose the sides with brick, stone, or terra-cotta, add windows and doors and elevators, and it is complete.

Fortunately for the stability of these high buildings, the effect of wind pressures had been studied in this country in the designs of the Kinzua, Pecos and other high viaducts.

All this had been thoroughly worked out and known to our engineers before the fall of the Tay Bridge in Scotland. That disastrous event led to very careful experiments on wind pressures by Sir Benjamin Baker, the very eminent engineer of the Forth Bridge. His experiments showed that a wind gauge of 300 square feet area showed a maximum pressure of thirty-five pounds per square foot, while a small one of one and one-half square feet area registered gusts of forty-one pounds per foot.

The modern elevated railway of cities is simply a very long railway viaduct. Some idea may be gained of the life of a modern riveted-iron structure from the experience of the Manhattan Elevated Railway of New York. These roads were built in 1878-79 to carry uniform loads of 1,600 pounds per lineal foot, except Second avenue, which was made to carry 2,000. The stresses were below 10,000 pounds per square inch.

These viaducts have carried in twenty-two years over 25,000,000 trains, weighing over 3,000,000,000 tons, at a maximum speed of twenty-five miles an hour, and are still in good order.

Bridge engineers of the present day are free from the difficulties which confronted the early designers of iron bridges. The mathematics of bridge design was understood in 1870, but the proportioning of details had to be worked out individually. Every new span was a new problem. Now the engineer tells his draughtsman to design a span of a given length, height and width, and to carry such a load. By the light of experience he does this at once.

Connections have become standardized so that the duplication of parts can be carried to its fullest extent.

Machine tools are used to make every part of a bridge, and power riveters to fasten them together. Great accuracy can now be had, and the sizes of parts have increased in a remarkable degree.

We have now great bridge companies, which are so completely equipped with appliances for both shop drawings and construction that the old joke becomes almost true that they can make bridges and sell them by the mile.

All improvements of design are now public property. All that the bridge companies do is done in the fierce light of competition. Mistakes mean ruin, and the fittest only survives.

Having such powerful aids, the American bridge engineer of to-day has advantages over his predecessors and over his European brethren, where the American system has not yet been adopted.

The American system gives the greatest possible rapidity of erection of the bridge on its piers. A span of 518 feet, weighing 1,000 tons, was erected at Cairo on the Mississippi in six days. The parts were not assembled until they were put upon the falseworks. European engineers have sometimes ordered a bridge to be rivetted together complete in the maker's yard, and then taken apart.

The adoption of American work in such bridges as the Atbara in South Africa, the Gokteik viaduct in Burmah, 320 feet high, and others, was due to low cost, quick delivery and erection, as well as excellence of material and construction.

FOUNDATIONS, &C.

Bridges must have foundations for their piers. Up to the middle of the nineteenth century engineers knew no better way of making them than by laying bare the bed of the river by a pumped-out cofferdam, or by driving piles into the sand, as Julius Cæsar did. About the middle of the century a French engineer conceived the first plan of a pneumatic foundation, which led to the present system of compressing air by pumping it into an inverted box, called a caisson, with airlocks on top to enable men and materials to go in and out. After the soft materials were removed, and the caisson sunk by its own weight to the proper depth, it was filled with concrete. The limit of depth is that in which men can work in compressed air without injury, and this is not much over one hundred feet.

The foundations of the Brooklyn and St. Louis bridges were put down in this way.

In the construction of the Poughkeepsie Bridge over the Hudson in 1887-88, it became necessary to go down 135 feet below tide level before hard bottom was reached. Another process was invented to take the place of compressed air. Timber caissons were built, having double sides, and the spaces between them filled with stone to give weight. Their tops were left open and the American single-bucket dredge was used. This bucket was lowered and lifted by a very long wire rope worked by the engine, and with it the soft material was removed. By moving this bucket to different parts of the caisson its sinking was perfectly controlled, and the caisson finally placed in its exact position, and perfectly vertical. The internal space was then filled with concrete laid under water by the same bucket, and levelled by divers when necessary.

While this work was going on, the Government of New South Wales in Australia called for both designs and tenders for a bridge over an estuary of the sea called Hawkesbury. The conditions were the same as at Poughkeepsie, except that the soft mud reached to a depth of 160 feet below tide level.

The designs of the engineers of the Poughkeepsie Bridge were accepted, and the same method of sinking open caissons (in this case made of iron) was carried out with perfect success.

The erection of this bridge involved another difficult problem. The mud was too soft and deep for piles and staging, and the cantilever system in this site would have increased the cost.

A staging was built on a large pontoon at the shore, and the span erected upon it. The whole was then towed out to the bridge site at high tide. As the tide fell, the pontoon was lowered and the steel girder was placed gently on its piers. The whole operation was completed within six hours. The other five spans were placed in the same manner.

The same system was followed afterward by the engineer of the Canadian Pacific Railway in placing the spans of a bridge over the St. Lawrence, in a very rapid current. It is now used in replacing old spans by new ones, as it interrupts traffic for the least possible time.

The solution of the problems presented at Hawkesbury gave the second introduction of American engineers to bridge building outside of America. The first was in 1786, when an American carpenter or shipwright built a bridge over Charles River at Boston, 1,470 feet long by 43 feet wide. This bridge was of wood supported on piles. His work gained for him such renown that he was called to Ireland and built a similar bridge at Belfast.

Tunnelling by compressed air is a horizontal application of compressed air foundations. The earth is supported by an iron tube, which is added to in rings, which are pushed forward by hydraulic jacks.

A tunnel is now being made under an arm of the sea between Boston and East Boston, some 1,400 feet long and 65 feet below tide. The interior lining of iron tubing is not used. The tunnel is built of concrete, reenforced by steel rods. This will effect a considerable economy. Success in modern engineering means doing a thing in the most economical way consistent with safety.

The St. Clair tunnel, which carries the Grand Trunk Railway of Canada under the outlet of Lake Huron, is a successful example of such work. Had the North River tunnel, at New York, been designed on equally scientific principles, it would probably have been finished, which now seems problematical.

The construction of rapid transit railways in cities is another branch of engineering, covering structural, mechanical and electrical engineering. Some of these railways are elevated, and are merely railway viaducts, but the favorite type now is that of subways. There are two kinds, those near the surface, like the district railways of London, the subways in Paris, Berlin and Boston, and that now building in New York. The South London and Central London and other London projects are tubes sunk fifty to eighty feet below the surface and requiring elevators for access. These are made on a plan devised by Greathead, and consist of cast-iron tubes pushed forward by hydraulic rams, and having the space outside of the tube filled with liquid cement pumped into place.

The construction of the Boston subway was difficult on account of the small width of the streets, their great traffic, and the necessity of underpinning the foundations of buildings. All of this was successfully done without disturbing the traffic for a single day, and reflects great credit on the engineer. Owing to the great width of New York streets, the problem is simpler in that respect, but requires skill in design and organization to complete the work in a short time. Although many times as long as the Boston subway, it will be built in nearly the same time. The design, where in earth, may be compared to that of a steel office building twenty miles long, laid flat on one of its sides. The reduplication of parts saves time and labor, and is the key to the anticipated rapid progress. Near the surface this subway is in open excavation, and tunnelling is confined to rock.

The construction of power houses for developing energy from coal and from falling water requires much structural besides electrical and mechanical engineering ability. The Niagara power house is intended to develop 100,000 horse power; that at the Sault Ste. Marie as much; that on the St. Lawrence, at Lachine, 70,000 horse power. These are huge works, requiring tunnels, rock-cut chambers, and masonry and concrete in walls and dams. They cover large extents of territory.

The contrast in size of the coal-using power houses is interesting. The new power house now building by the Manhattan Elevated Railway, in New York, develops in the small space of 200 by 400 feet 100,000 horse power, or as much power as that utilized at Niagara Falls.

One of the most useful materials which modern engineers now make use of is concrete, which can be put into confined spaces and laid under water. It costs less than masonry, while as strong. This is the revival of the use of a material used by the Romans. The writer was once allowed to climb a ladder and look at the construction of a dome of the Pantheon, at Rome. He found it a monolithic mass of concrete, and hence without thrust. It is a better piece of engineering construction than the dome of St. Peter's, built fifteen hundred years later. The dome of Columbia College Library in New York is of concrete.

Concrete is a mixture of broken stone or gravel, sand, and Portland cement. Its virtue depends upon the uniform good quality of the cement. The use of the rotary kiln, which exposes all of the contained material to a uniform and constant intense heat, has revolutionized the manufacture of Portland cement. The engineer can now depend upon its uniformity of strength.

Wheels, axles, bridges, and rails have all been strengthened to carry their increased loads; but, strange to say, the splices which hold in place the ends of the rails, and which are really short-span bridges, are now the weakest part of a railway. The angle-bar splice has but one-third of the strength of the rail, and its strength cannot be increased, owing to its want of depth. Joints go down under every passing wheel, and the ends of the rails wear out long before the rest.

This is not an insignificant detail. It has been estimated by the officers of one of the trunk lines that a splice of proper design and strength would save yearly enough in track labor (most of which is expended in tamping up low joints) to buy all the new rails and fastenings required in some time. It would save much more than that in the wear of rolling stock. A perfect joint would be an economic device next in value to the Bessemer steel rail. Here is a place for scientific and practical skill.

HYDRAULIC ENGINEERING.

Hydraulic engineering is one of the oldest branches of engineering, and was developed before the last century. The irrigation works of Asia, Africa, Spain, Italy, the Roman aqueducts and the canals of Europe are examples. Hydraulic works cannot be constructed in ignorance of the laws which govern the flow of water. The action of water is relentless, as ruined canals, obstructed rivers and washed-out dams do testify.

The principal additions of the nineteenth century to hydraulic engineering are the collection of larger statistics of the flow of water in pipes and channels, of rainfall, run-off and available supply. It is now known that the germs of disease can be retained by ordinary sand filters, and it is now an established fact that pure drinking water and proper drainage are sure preventives of typhoid and similar fevers. Very foul water can be made potable. Experiments show that the water of the Schuylkill River at Philadelphia, which contains 400,000 germs in the space of less than a cubic inch, was so much purified by filtering that only 60 remained. This is a discovery of sanitary science, but the application of it is through structural engineering, which designs and executes the filter beds with great economy.

The removal of sewage, after having been done by the Etruscans before the foundation of Rome, became a lost art during the dirty Dark Ages, when filth and piety were deemed to be connected in some mysterious way. It was reserved for good John Wesley to point out that "Cleanliness is next to Godliness." Now sewage works are as common as those for water supply. Some of them have been of great size and cost. Such are the drainage works of London, Paris, Berlin, Boston, Chicago and New Orleans. A very difficult work was the drainage of the City of Mexico, which is in a valley surrounded by mountains, and elevated only four to five feet above a lake having no outlet. Attempts to drain the lake have been made in vain for six hundred years. It has lately been accomplished by a tunnel six miles long through the mountains, and a canal of over thirty miles, the whole work costing some $20,000,000.

The drainage of Chicago by locks and canal into the Illinois River has cost some $35,000,000, and is well worth its cost.

Scientific research has been applied to the designing of high masonry and concrete dams, and we know now that no well-designed dam on a good foundation should fail. The dams now building across the Nile by order of the British Government will create the largest artificial lakes in the world. The water, thus stored, will be of inestimable value in irrigating the crops of lower Egypt. Their cost, although great, will not exceed the sums spent by lavish Khedive Ismail on useless palaces, now falling to decay.

The Suez Canal is one of the largest hydraulic works of the last century, and is a notable instance of the displacement of hand labor by the use of machinery. Ismail began by impressing a large part of the peasant population of Egypt, just as Rameses had done over 3,000 years before. These unfortunate people were set to dig the sand with rude hoes, and carry it away in baskets on their heads. They died by thousands for want of water and proper food. At last the French engineers persuaded the Khedive to let them introduce steam dredging machinery. A light railway was laid to supply provisions, and a small ditch dug to bring pure water. The number of men employed fell to one-fourth. Machinery did the rest. But for this the canal would never have been finished.

The Panama Canal now uses the best modern machinery, and the Nicaragua Canal, if built, will apply still better methods developed on the Chicago Drainage Canal, where material was handled at a less cost than has ever been done before.

Russia is better supplied with internal waterways than any other country. Her rivers rise near each other, and have long been connected by canals. It is stated that she has over 60,000 miles of internal navigation, and is now preparing the construction of canals to connect the Caspian with the Baltic Sea.

The Erie Canal was one of very small cost, but its influence has been surpassed by none. The "winning of the West" was hastened many years by the construction of this work in the first quarter of the century. Two horses were just able to draw a ton of goods at the speed of two miles an hour over the wretched roads of those days. When the canal was made these two horses could draw a boat carrying 150 tons four miles an hour. Mud, or, in other words, friction, is the great enemy of civilization, and canals were the first things to diminish it, and after that railways.

The Erie Canal was made by engineers, but it had to make its own engineers first, as there was none available in this country at that time. These self-taught men, some of them land surveyors and others lawyers, showed themselves the equals of the Englishmen Brindley and Smeaton, when they located a water route through the wilderness, having a uniform descent from Lake Erie to the Hudson, which would have been so built if there had been enough money.

The question now is whether to enlarge the capacity of this canal by gravity, enlarging its prism and locks, or to increase speed and move more boats in a season by electrical appliances. The last method seems more in line with those of the present.

There should be a waterway from the Hudson to Lake Erie large enough for vessels able to navigate the Lakes and the ocean. A draught of twenty-one feet can be had at a cost estimated at $200,000,000.

The deepening of the Chicago Drainage Canal to the Mississippi River, and the deepening of the Mississippi itself to the Gulf of Mexico, is a logical sequence of the first project. The Nicaragua Canal would then form one part of a great line of navigation, by which the products of the interior of the continent could reach either the Atlantic or Pacific Ocean.

The cost would be small compared with the resulting benefits, and some day this navigation will be built by the Government of the United States.

The deepening of the Southwest Pass of the Mississippi River from six to thirty feet by James B. Eads was a great engineering achievement. It was the first application of the jetty system on a large scale. This is merely confining the flow of the river, and thus increasing its velocity so that it secures a deeper channel for itself.

The improvement of harbors follows closely the increased size of ocean and lake vessels. The approach to New York harbor is now being deepened to forty feet, a thing impossible to be done without the largest application of steam machinery in a suction dredge boat.

The great increase of urban population, due to steam and electric railways, has made works of water supply and drainage necessary everywhere. Some of these are on a very grand scale. An illustration of this is the Croton Aqueduct of New York as it now is, and as it will be hereafter.

This work was thought by its designers to be on a scale large enough to last for all time. It is now less than sixty years old, and the population of New York will soon be too large to be supplied by it.

It is able to supply 250,000,000 to 300,000,000 gallons daily, and its cost, when the Cornell dam and Jerome Park reservoir are finished, will be a little over $92,000,000.

It is now suggested to store water in the Adirondack Mountains, 203 miles away, by dams built at the outlet of ten or twelve lakes. This will equalize the flow of the Hudson River so as to give 3,000,000,000 to 4,000,000,000 gallons daily. It is then proposed to pump 1,000,000,000 gallons daily from the Hudson River at Poughkeepsie, sixty miles away, to a height sufficient to supply the city by gravity through an aqueduct. This water would be filtered at Poughkeepsie, and we now know that all impurities can be removed.

If this scheme is carried out, the total supply will be about 1,300,000,000 gallons daily, or enough for a population of from 12,000,000 to 13,000,000 persons. By putting in more pumps, filter beds, and conduits, this supply can be increased 40 per cent. or to 1,800,000,000 gallons daily. This water would fill every day a lake one mile square by ten feet deep. This is a fair example of the scale of the engineering works of the nineteenth and twentieth centuries.

By the application of modern labor-saving machinery, the cost of this work can be so far controlled that the cost to the city of New York per 1,000,000 gallons would be no greater than that of the present Croton supply.

All works of hydraulic engineers depend on water. But what will happen if the water all dries up? India, China, Spain, Turkey and Syria have suffered from droughts, caused clearly by the destruction of their forests. The demand for paper to print books and newspapers upon, and for other purposes, is fast converting our forests into pulp. We cannot even say, "After us the deluge," for it will seldom rain in those evil days. When the rains do come, the spongelike vegetation of the forests being gone, the streams will be torrents at one time of the year and dried up during the rest, as we now see in the arid regions of the West.

MECHANICAL ENGINEERING.

Mechanical engineering is employed in all dynamical engineering. It covers the designs of prime motors of all sorts, steam gas, and gasolene reciprocating engines; also, steam and water turbines, windmills, and wave motors.

It comprises all means of transmitting power, as by shafting, ropes, pneumatic pressure, and compressed air, all of which seem likely to be superseded by electricity.

It covers the construction of machine tools and machinery of all kinds. It enters into all the processes of structural, hydraulic, electrical, and industrial engineering. The special improvements are the almost universal use of rotary motion, and of the reduplication of parts.

The steam engine is a machine of reciprocating, converted into rotary, motion by the crank. The progress of mechanical engineering during the nineteeth century is measured by the improvements of the steam engine, principally in the direction of saving fuel, by the invention of internal combustion or gas engines, the application of electrical transmission, and, latest, the practical development of steam turbines, by Parsons, Westinghouse, De Laval, Curtis, and others. In these a jet of steam impinges upon buckets set upon the circumference of a wheel. It was clearly indicated by the Italian engineer Bronca, in 1629, but he was too early. The time was not ripe, and there were then no machine tools giving the perfection of workmanship required.

Their advantages are that their motion is rotary and not reciprocal. They can develop speed of from 5,000 to 30,000 revolutions per minute, while the highest ever attained by a reciprocating engine is not over 1,000. Their thermodynamic losses are less, hence they consume less steam and less fuel.

It is a very interesting fact that the basic invention upon which not only steam turbines and electric dynamos, but indeed all other parts of mechanical engineering, depend, is of such remote antiquity that we know nothing of its origin. This is the wheel, which Gladstone said was the greatest of man's mechanical inventions, as there is nothing in nature to suggest it.

Duplication of parts has lowered the cost of all products. Clothing is one of these. The parts of ready-made garments and shoes are cut into shape in numbers at a time, by sharp-edged templates, and fastened together by sewing machines.

Mechanical engineering is a good example of the survival of the fittest. Millions of dollars are expended on machinery, when suddenly a new discovery or invention casts them all into the scrap heap, to be replaced by those of greater earning capacity.

Prime motors derive their energy either from coal or other combinations of carbon, such as petroleum, or from gravity. This may come from falling water, and the old-fashioned water wheels of the eighteenth century were superseded in the nineteenth by turbines, first invented in France and since greatly perfected. These are used in the electrical transmission of water power at Niagara of 5,000 horse power, and form a very important part of the plant.

The other gravity motors are windmills and wavemotors. Windmills are an old invention, but have been greatly improved in the United States by the use of the self-reefing wheel. The great plains of the West are subject to sudden, violent gales of wind, and unless the wheel was automatically self-reefing it would often be destroyed. Little has been written about these wheels, but their use is very widely extended, and they perform a most useful function in industrial engineering.

There have been vast numbers of patents taken out for wave motors. One was invented in Chili, South America, which furnished a constant power for four months and was utilized in sawing planks. The action of waves is more constant on the Pacific coast of America than elsewhere, and some auxiliary power, such as a gasolene engine, which can be quickly started and stopped, must be provided for use during calm days. The prime cost of such a machine need not exceed that of a steam plant, and the cost of operating is much less than that of any fuel-burning engine. The saving of coal is a very important problem. In a wider sense, we may say that the saving of all the great stores which nature has laid up for us during the past, and which have remained almost untouched until the nineteenth century, is *the* great problem of to-day.

Petroleum and natural gas may disappear. The ores of gold, silver and platinum will not last forever. Trees will grow, and iron ores seem to be practically inexhaustible. Chemistry has added a new metal in aluminum, which replaces copper for many purposes. One of the greatest problems of the twentieth century is to discover some chemical process for treating iron, by which oxidation will not take place.

Coal, next to grain, is the most important of nature's gifts; it can be exhausted or the cost of mining it become so great that it cannot be obtained in the countries where it is most needed; water, wind and wave power may take its place to a limited extent, and greater use may be made of the waste gases coming from blast or smelter furnaces, but as nearly all energy comes from coal, its use must be economized, and the greatest economy will come from pulverizing coal and using it in the shape of a fine powder. Inventions have been made trying to deliver this powder into the fire box as fast as made, for it is as explosive as gunpowder, and as dangerous to store or handle. If this can be done, there will be a saving of coal due to perfect and smokeless combustion, as the admission of air can be entirely regulated, the same blast which throws in the powder furnishing oxygen. Some investigators have estimated that the saving of coal will be as great as 20 per cent. This means 100,000,000 tons of coal annually.

Bituminous coal will then be as smokeless as anthracite, and can be burned in locomotives. Cities will be free from the nuisance of wasted coal, which we call soot. This process will be the best kind of mechanical stoking, and will prevent the necessity of opening the doors of fire boxes. The boiler rooms of steamships will no longer be "floating hells," and the firing of locomotives will become easy.

Another problem of mechanical engineering is to determine whether it will be found more economical to transform the energy of coal, at the mines, into electric current and send it by wire to cities and other places where it is wanted, or to carry the coal by rail and water, as we now do, to such places, and convert it there by the steam or gas engine.

In favor of the first method it can be said that hills of refuse coal now representing locked-up capital can be burned, and the cost of transportation and handling be saved. Electric energy can now transport power in high voltage economically between coal mines and most large cities.

The second method has the advantage of not depending on one single source of supply that may break down, but in having the energy stored in coal pockets nearby the place of use, where it can be applied to separate units of power with no fear of failure.

It seems probable that a combination of the two systems will produce the best results. Where power can be sent electrically from the mines for less cost than the coal can be transported, that method will be used.

To prevent stoppage of works, the separate motors and a store of coal, to be used in cases of emergency, will still be needed, just as has been described as necessary to the commercial success of wave motors.

ELECTRICAL ENGINEERING.

Any attempt by the writer of this article to trace the progress of electricity would be but a vain repetition, after the admirable manner in which the subject has been treated in a former paper of this series by Prof. Elihu Thomson.

We can only once more emphasize the fact that it is by the union of four separate classes of minds scientific discoverers, inventors, engineers and capitalists that this vast new industry has been created, which gives direct employment to thousands, and, as Bacon said 300 years ago, has "endowed the human race with new powers."

METALLURGY AND MINING.

All the processes of metallurgy and mining employ statical, hydraulic, mechanical and electrical engineering. Coal, without railways and canals, would be of little use, unless electrical engineering came to its assistance.

It was estimated by the late Lord Armstrong that of the 450,000,000 to 500,000,000 tons of coal annually produced in the world, one-third is used for steam production, one-third in metallurgical processes, and one-third for domestic consumption. This last item seems large. It is the most important manufacturing industry in the world, and may be seen by comparing the coal-less condition of the eighteenth century with the coal-using condition of the nineteenth century.

Next in importance comes the production of iron and steel. Steel, on account of its great cost and brittleness, was only used for tools and special purposes until past the middle of the last century. This has been all changed by the invention of his steel by Bessemer in 1864, and open-hearth steel in the furnace of Siemens, perfected some twenty years since by Gilchrist & Thomas.

The United States have taken the lead in steel manufacture. In 1873, Great Britain made three times as much steel as the United States. Now the United States makes